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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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The signalling content of asset prices for inflation: Implications for Quantitative Easing *

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Abstract

We investigate the information content of financial variables as signalling devices of two abnormal inflationary regimes: (1) very low inflation or deflation, and (2) high inflation. Specifically, we determine the information content of equity and house prices, private credit volumes, and sovereign and corporate bond yields, for 11 advanced economies over the past three decades, using both the receiver operating characteristic (ROC) curve and a logit model. The outcomes show that high asset prices more often signal high inflation than low inflation/deflation. However, in some countries, high asset prices and low bond yields are a significant indicator of low inflation or deflation as well. The transmission time of financial developments to inflation can be quite long (up to 8 quarters). For monetary policy, these findings imply that stimulating asset prices through Quantitative Easing (QE) can effectively influence inflation, but that the effects are quite uncertain, both in timing and direction.

Keywords: Quantitative Easing, Inflation, Financial markets.
JEL classifications: E31, E44, E52.

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1. Introduction

The debate about the relation between monetary policy and financial stability has taken a new twist by the large scale asset purchase programs of central banks. These quantitative easing (QE) programs are intended to loosen the monetary stance at the zero lower bound, in order to combat low inflation and weak economic growth. Indeed, simulations show that QE has succeeded in providing significant support to output and inflation; in the absence of QE inflation would have been negative longer (Praet, 2016; Wieladek and Pascual, 2016). On the other hand, QE drives interest rates and risk spreads lower, thereby stimulating risk-taking in financial markets. In fact, this is the main mechanism in the portfolio rebalancing channel of QE (see Joyce et al., 2012). Since asset purchases by the central bank change the composition of investment portfolios, preferred-habitat investors will react by buying assets which are a close substitute to the assets sold. This process will raise the price of assets not purchased by the central bank as well. Low interest rates and high risk-taking are obvious ingredients for financial imbalances and asset price bubbles. Figure 1 shows that in the UK, the US and the euro area, stock prices rose strongly after announcements of new QE programs.

[insert Figure 1]

While monetary policy makers acknowledge that QE raises financial imbalances (Draghi, 2015; Yellen, 2014), such concerns are usually assessed to be secondary to the risk of not reaching the inflation target. In this view, the risk of financial imbalances is a side-effect that has to be dealt with by macroprudential policy. For instance, ECB president Draghi said that the ECB monitors closely any potential financial stability risks of QE, but that bubbles (of a local nature) should be addressed by macro-prudential instruments rather than by monetary policy (Draghi, 2015). Fed chairwoman Yellen made similar remarks, arguing that monetary policy faces significant limitations as a tool to promote financial stability and that macroprudential policy needs to play the primary role in addressing financial imbalances (Yellen, 2014). At the same time, she acknowledged that the search for yield in a low interest rate environment may limit the effectiveness of macroprudential measures, which may make an adjustment in monetary policy more appropriate to address financial stability risks.

The main reason for central banks to take into account asset price inflation in monetary policy is its – long run – downward risks for price stability (Papademos and Stark, 2010). Empirical studies provide evidence for this. Reinhart and Reinhart (2010) estimate that inflation turns out to be 4 percentage points lower after the bursting of an asset price bubble. Alessie and Detken (2011) relate substantial adverse economic effects to high-cost boom-bust cycles, which lead to a sharp drop in aggregate demand and raise deflationary risks, both via wealth effects and via a credit crunch in the financial sector. Based on signalling methods they identify several financial variables as leading indicators of costly boom-bust cycles.

Another reason to take into account asset prices in monetary policy is that macroprudential tools are sometimes insufficient to deal with risks that originate in sectors outside the scope of regulators (e.g. shadow banks). Stein (2013) therefore argues that monetary policy reactions to financial market developments may sometimes be needed. Recent literature confirms that a combined approach of macroprudential and monetary policy leads to better outcomes in terms of lower volatility of output and inflation, see for instance Gelain and Ilbas (2014), Lambertini et al. (2013), Angelini el al. (2012), Bauducco et al. (2010) and N'Diaye (2009). However, co-ordinating macroprudential and monetary policy can be complex. This most likely comes to the fore when the risks for price stability and financial stability are diverging and the central bank faces trade-offs that are potentially costly. This may be the case in the current situation, where a very low level of inflation motivates a loosening of monetary policy conditions and QE, at the risk of fuelling asset price bubbles.

The trade-off between financial stability and price stability is complicated since it poses an intertemporal co-ordination problem. Monetary policy usually aims at (consumer) price stability at a medium-term horizon, while imbalances in credit and asset prices usually take a long time to build up and unwind (Borio and Lowe, 2002). Nevertheless, the latter may convey information about long-term risks to price stability. A central bank that takes those financial market signals into account may have to trade-off current and future stability (Shirakawa, 2009). Optimising this trade-off could imply that the central bank allows inflation to deviate from its target in the short term, as advocated by Borio and White (2004).

Even if there is flexibility in policy focus and horizon, co-ordination issues remain. Monetary and prudential measures may have different effects initially and work out with different lags. There can also be sequencing issues, for instance, the issue of whether macroprudential tools should be the first that policymakers deploy to lean against financial imbalances or not. Another issue is how much weight should be given to monetary and macroprudential instruments in situations of a trade-off between price and financial stability.

Our paper is motivated by the trade-off that central banks currently face in decisions on QE. This monetary instrument deliberately stimulates asset prices, since this is a main channel through which QE influences aggregate demand and inflation. However, by encouraging risk-taking by market participants, QE may create asset price bubbles when asset price developments are out of sync with economic fundamentals. The bursting of such bubbles may (in the longer term) even exacerbate the deflationary tendencies which central banks try to address with QE. Hence for monetary policy it is important to know whether asset price developments are indicating future (upward and downward) risks to price stability and at which lag.

We investigate the information content of financial variables such as stock prices, private credit and interest rates, as signalling devices of two possible inflationary regimes (defined as inflation deviating more than 1 standard deviation from its mean): (1) very low inflation or deflation, and (2) very high inflation. So our approach focusses on the tail risks to inflation and not on inflation developments as such. We employ two methodologies: the signalling approach and the discrete choice modelling approach, respectively. For the signalling approach, which is a non-parametric approach, we use the receiver operating characteristic (ROC) curve. This method has recently become more popular among economists, because it fully maps all possible trade-offs between Type I and Type II errors (i.e., missed signals and false alarms, respectively).[1] For example, Drehmann and Juselius (2014) and Detken et al. (2014) use ROC to find early warning indicators (EWI) of banking crises. The second methodology, the discrete choice modelling approach, is parametric. We use a logit model, mapping various explanatory variables into the probability of a high (low) inflationary regime. An important difference between these two approaches is that signalling extraction determines the signalling content of each financial variable separately, while the logit model gives the joint probability determined by several financial variables taken together.

Our results indicate that high asset prices (i.e. above their trend values) are more often signalling high inflation than low inflation/deflation. In some countries, high asset prices are a significant indicator of low inflation as well. In the UK, Japan and Netherlands, high credit, equity and house prices are both signalling very high and very low inflation. The lead times indicate that the transmission of high credit and asset prices to episodes of very low inflation/deflation can be quite long, ranging up to eight quarters. Low government bond yields (vis-à-vis their mean

[1] Hence, ROC analysis does not require a specification of the policymaker's utility function with respect to Type I and Type II errors, as is the case in studies that follow the signalling approach of Kaminsky et al. (1998). For instance, Alessi and Detken (2011), testing the performance of real and financial variables as early warning indicators of costly aggregate asset price boom-bust cycles, specify a loss function for the policymaker.

values), as a rule, do not give a significant signal for high inflation, while they do for low inflation/deflation. Government bond yields can affect inflation indirectly, through their effect on credit and asset prices, sometimes leading to boom-bust cycles. Outcomes of complementary logit models confirm that financial variables are important in explaining high and low inflation regimes. These results indicate that stimulating asset prices – one of the main transmission channels of QE - can be effective in influencing inflation. However the effects are quite uncertain, both in timing and direction. The results for a few countries in our sample indicate that the asset price (or portfolio rebalancing) channel can have perverse effects, which may work against the objectives of QE.

The rest of this paper is organised as follows. In section 2 the empirical strategy is explained. Section 3 describes the transmission channels that link credit, interest rates and asset prices to inflation and defines the data used in the ROC analysis. Section 4 presents the results and discusses its policy implications. Section 5 concludes.

2. Empirical strategy

In this section, we discuss signalling extraction, the use of ROC curve analysis for signalling extraction, followed by an explanation of the logit modelling approach.

2.1 Signalling extraction

We will distinguish between cases of 'abnormal inflation' and control for cases of 'normal inflation'. Abnormal inflation is defined as either very high inflation or very low inflation/deflation. Our search is for a marker or indicator that issues a signal within a predefined lead time when a period of abnormal inflation is ahead, while not issuing a signal when inflation stays normal. Then, the matrix in Figure 2 gives the possible outcomes. When a signal is issued and abnormal inflation occurs within a predefined horizon, it is classified as a correct signal or 'true positive' (cell A). If, on the other hand, inflation stays normal, it is classified as a false signal or 'false positive' (B). When no signal is issued and abnormal inflation does occur within the predefined horizon, it is classified as an incorrect or missing signal (C) while, if inflation stays normal, it is classified as a correct signal or 'true negative' (D).

[insert Figure 2]

The following definitions in the signalling literature are common:

True positive rate, Signal ratio or 'Sensitivity' = A/(A + C) (1)

Type I error rate = 1- Sensitivity = C/(A + C) (2)

Type II error rate, 'False positive rate' or 'Noise ratio' = B/(B + D) (3)

Noise-to-signal ratio = (3)/(1) = [B/(B + D)]/[A/(A + C)] (4)

The noise-to-signal ratio (4) is often used to compare the signalling qualities of different indicator variables or models for a given threshold. A lower noise-to-signal ratio indicates better signalling power. The problem with the noise-to-signal ratio is that it relies on a specific threshold and often reaches its minimum value at both very low noise and signal ratios (Detken et al., 2014). This minimum will usually be accomplished by setting the threshold very high, as the higher the threshold, the fewer signals will be issued. A high threshold would imply that the policy maker is extremely averse to false alarms and puts little penalty on missed signals. Therefore, we use ROC curve analysis which has as advantage that it takes all possible thresholds into account.[2]

2.2 ROC curve analysis

The ROC curve plots the noise ratio or false positive rate (3) against the signal ratio or true positive rate (1) for every possible threshold value. Figure 3 gives two stylized ROC curves, ROC1 and ROC2. These curves reflect the trade-off between Type I and Type II error rates. High thresholds are close to the origin (with few signals issued, few abnormal inflation episodes are correctly identified and few incorrectly signalled), whereas low thresholds are close to the (1; 1) point (with many signals issued, many abnormal inflation episodes are correctly classified but many false signals will also be issued).

[2] Alternatively, one can calculate an optimal threshold by minimising an explicit loss function, which takes account of the presumed policymaker's preferences with regard to Type I and Type II errors (e.g., Alessi and Detken (2011) with respect to signalling asset price boom-bust cycles; De Haan and Kakes (2012) with respect to insolvencies among insurance companies). The problem is that this choice of policy preference is arbitrary.

[Insert Figure 3]

The area under the ROC curve (AUROC) captures an indicator's forecasting performance in a single measure. It may be seen as a generalisation of the conventional noise-to-signal method, with the advantage that it does not depend on a specific threshold above which a signal is triggered. AUROC ranges from 0 to 1. A value of 1 (meaning that the curve coincides with the horizontal and vertical axis) indicates a perfect indicator: zero Type I and Type II errors. An AUROC of 0.5, in which case ROC lies exactly on the 45 degree line, implies that the indicator is uninformative. Let us assume that ROC1 is derived for indicator 1 and ROC2 for indicator 2. ROC1 in the figure lies above the 45 degree line. Hence, AUROC1 in the figure is greater than 0.5. An AUROC greater than 0.5 means that high values of indicator 1 signal an abnormal inflationary episode. This is used as a reference value for assessing the signalling quality of high levels of credit volumes, house prices and equity prices. High asset prices are relevant for our paper in the context of QE. In contrast to ROC1, ROC2 lies below the 45 degree line. Hence, AUROC2 is smaller than 0.5. This means that low instead of high values of indicator 2 signal an abnormal inflationary episode.[3] This is used as a reference value for assessing the signalling quality of low sovereign and corporate bond yields. Low rates are relevant for our paper in the context of QE. To facilitate direct comparison with AUROC1, we transform AUROC2 into [1 – AUROC2]. Hence, both AUROC1 and [1 – AUROC2] should be higher than 0.5 for a good signalling quality of indicator 1 and indicator 2, respectively.

ROC analysis works with a dichotomous variable (abnormal versus normal). Since we are interested in abnormal inflation, which can either be very high inflation or very low inflation/deflation, we perform two separate ROC analyses. First, we calculate ROC curves assessing the ability of financial variables to signal episodes of very high inflation (versus normal inflation). Second, ROC curves are determined for the signalling quality with respect to low inflation/deflation (versus normal inflation).

2.3 Logit model

The logit model is a parametric discrete choice model. This model maps various explanatory variables together into a joint probability of a high (low) inflationary regime. The main difference of this approach with nonparametric signalling extraction discussed in the previous

[3] ROC1 and ROC2 are deliberately drawn as mirror images around the 45 degree line, so that AUROC1 = 1 – AUROC2.

subsection is that the latter determines the signalling content of each financial variable $x_1, x_2, \ldots$ separately with respect to the inflationary regime, while the logit model gives the joint probability of a particular inflationary regime as determined by a vector of several financial variables (**x**) taken together.

Formally, the logit model estimates the probability p that a binary response variable y = [0, 1] has value $y = 1$ given the outcomes of a set of independent variables **x**:

$$p = \mathrm{pr}[y = 1|\mathbf{x}] = \mathrm{F}(\mathbf{x}'\beta) \qquad (5)$$

For the logit model, $\mathrm{F}(\mathbf{x}'\beta)$ is the cumulative distribution function of the logistic distribution:

$$\Lambda(\mathbf{x}'\beta) = \frac{e^{\mathbf{x}'\beta}}{1+e^{\mathbf{x}'\beta}}\ , \qquad (6)$$

where the predicted probabilities are limited between 0 and 1.

3. Financial variables considered as inflation indicators

In this section, we first discuss the channels through which credit and asset prices transmit to inflation and then introduce our selection of financial variables as indicators of future inflation.

3.1 Transmission channels

Credit and asset price developments can affect price stability though various channels. There are direct links between credit and (consumer price) inflation through the standard transmission channels in the presence of financial frictions (Hellwig, 2000). For instance, a cash-in-advance constraint requires that agents need money or credit to purchase goods, through which aggregate demand and thereby inflation is affected (see Figure 4, channel 1).

[insert Figure 4]

Another channel through which asset prices can affect consumer prices is wealth effects. Rising house and equity prices create valuation gains for the holders of such assets, increasing their spending power (Sousa, 2009). Spending power is also influenced by the level of the interest rate, since it determines disposable income. This affects aggregate consumer demand and thereby consumer prices, see Figure 4, channel 2a. Rising equity prices also stimulate investments of firms via a Tobin's q effect (Tobin, 1969), Figure 4, channel 2b. These transmission channels can lead to both high inflation (when asset prices are booming and/or interest rates are very low) and low inflation (when asset prices are declining and/or interest rates are high).

Credit and asset prices can similarly affect the economy and hence inflation through the financial accelerator (Bernanke, Gertler and Gilchrist, 1996), see Figure 4, channel 3. Through this channel, developments in credit supply, which interact with asset prices via collateral values, propagate and amplify shocks to the macroeconomy. The key mechanism involves the link between the external finance premium and the net worth of potential borrowers, which is determined by asset prices. There also is a link between interest rates and asset prices through the risk-taking channel (Borio and Zhu, 2008). Low interest rates stimulate search for yield and thereby boost asset prices (Figure 4, channel 4). The financial accelerator and the risk taking channel can shape boom/bust cycles in financial markets and the economy (Figure 4, channel 5). Hence, excessive asset prices and credit developments can both precede high and low inflation. A boom can contribute to high inflation by boosting confidence and wealth effects (i.e., channel 5 can reinforce channel 2). However, if an asset price boom turns into a bust that triggers a financial crisis, the link between asset prices and consumer price inflation could go into the reverse and deflationary risks might appear. In the empirical literature, excessive credit developments have been found to lead to costly asset price boom-bust cycles, which are associated with deflation (Alessie and Detken, 2011). Such mechanisms would make the indicator properties of credit and asset prices depend on whether there is an asset price bubble or not (Figure 4, channel 5).

3.2 Data

In view of these theories on the relationship between credit, asset prices and inflation, we consider four financial variables as potential indicators of future inflation: credit, equity price, house price and bond yields. For bond yields, we consider both sovereign yields (with ten years maturity) and corporate bond rates.

Our data consists of quarterly time series from 11 countries (US, Japan, UK, Germany, France, Italy, Netherlands, Australia, Norway, Sweden and Spain). These are major advanced economies for which historic data is mostly available, especially for corporate bond yields and house prices. Figure 5 shows the four financial variables for the United States, as an example. The sample starts in 1985Q1 and ends in 2014Q4[4]. It is clear that asset prices and interest rates have trends. We presume that it is not the trend but the cyclical component in these series that may have some signalling content for inflation. Therefore, these series have been detrended in order to capture their cycles. For credit and asset prices we use ratios with respect to their trends, for the interest rates differences from their trends. The trends have been calculated using the Hodrick-Prescott filter with a smoothing parameter of 1600, as is conventional for quarterly time series. Definitions and sources of all variables can be found in Appendix A.

[insert Figure 5]

The inflationary regimes, which we aim to predict using the above mentioned financial variables as signalling devices, are defined for each country using the means and standard deviations over the sample period for the quarterly year-on-year inflation rates, as measured by the consumer price index. The regimes considered are:

1. Normal inflation = mean - 1 standard deviation ≤ inflation ≤ mean + 1 standard deviation (dummy1 = 0, dummy2 = 0);
2. High inflation = inflation > mean + 1 standard deviation (dummy1 = 1);
3. Low inflation = inflation < mean - 1 standard deviation (dummy2 = 1).

So we have two dummy variables that have values 0 and 1 depending on the inflationary regime. We first calculate ROC curves assessing the ability of financial variables to predict that dummy1 = 1 versus dummy1 = 0. Second, ROC curves are determined for the signalling quality with respect to dummy2 = 1 versus dummy2 = 0.

Figure 6 gives the inflationary regimes for the US, as an example. Mean inflation during the sample period was 2.77%, the standard deviation was 1.27. Hence, episodes with very high inflation are defined as inflation above 4.04% and low inflation/deflation as inflation below

[4] The sample starts in 1985 because since then in most advanced economies monetary policy strategies, following Volcker's example in the US, started aiming at achieving some goal of price stability. If data is not available over the full sample period, we use a shorter time period. See further Appendix A for details.

1.50%. In the case of the US, we so define 16 quarterly observations of very high inflation, 14 quarterly observations of very low inflation/deflation, and 86 quarters of normal inflation.[5] We repeat this procedure for all other ten countries in the sample; the results are summarized in Table 1.

[insert Figure 6 and Table 1]

4. Results

In this section, we present the results of the ROC analysis, followed by the results of the logit model estimation. We conclude the section with some policy implications.

4.1 ROC results

We calculate AUROC assuming nine different leading properties for the indicators with respect to inflation. This is done by lagging the inflationary regime dummy by 8 to 0 quarters, and derive AUROC for all lags.

Figure 7, panels a through f, shows the AUROC estimates for credit and asset prices (i.e. equity and house prices). 95% confidence bands are plotted for significance. To keep the analysis tractable, we present AUROC averaged over all 11 countries in the sample.[6] We define an indicator to produce a significant signal if the lower confidence band of AUROC is greater than 0.5 for at least one of the lags 8 to 0.

[insert Figure 7]

As explained in Section 2, we first calculate AUROC assessing the ability of financial variables to signal episodes of very high inflation (versus normal inflation). Second, AUROC is determined for the signalling quality with respect to low inflation/deflation (versus normal inflation).

[5] The number of quarters in the two opposite abnormal regimes need not be the same. It depends on the skewness of the distribution of inflation in the extreme regimes.
[6] Country specific ROC curves are available on request.

The AUROC estimates suggest that high asset prices (i.e. price levels exceeding the trend) are more often signalling high inflation than low inflation/deflation. Figure 7, panels a, c, e, shows that AUROC is significantly greater than 0.5 for several lags, while it is not significant for low inflation (panels b, d, f).

Figure 7, panels g through j, shows the [1 – AUROC] estimates for bond yields (sovereign and corporate bond yields, respectively), again averaged over all 11 countries. The results suggest that low bond yields as a rule do not give a significant signal for high inflation, while they do for low inflation/deflation. This appears from the values for [1 – AUROC] in Figure 7, panel h, which are significantly higher than 0.5, while those in panel g are not. Low corporate bond rates give an uninformative signal for either low and high inflation (Figures 7, panels i through j).

To also show country-specific estimates, Figure 8 plots the maximum signalling value found among lags 8 to 0 for each variable and each of the 11 countries, if statistically significant. Panel a plots the signalling value for high inflation, panel b for low inflation/deflation. Comparing the significant peak signals for high versus low inflation shows that high credit and asset prices and low interest rates give a stronger signal for high than for low inflation; the maximum significant signals for high inflation in panel a exceed the signals for low inflation in panel b in most cases. Nonetheless, in some countries, high asset prices are a significant indicator of low inflation as well. In the UK, Japan and Netherlands, high credit, equity and house prices are both signalling very high and very low inflation.

[insert Figure 8]

Panel a of Figure 8 also shows that a significant peak signal of the credit indicator of high inflation goes in tandem with a significant signal of the house price indicator in several countries, especially the UK, US and Japan. This finding reflects that credit and housing cycles are intertwined. Credit and house price developments both significantly influence inflation, usually upward according to their significant signals for high inflation. Credit and house prices can similarly affect the economy and hence inflation through the financial accelerator, as explained in Section 3.

Figure 9 plots the lead time corresponding to the significant peak signals shown in Figure 8. The lead times indicate that the transmission of high credit and asset prices to episodes of very low inflation/deflation can be quite long (in Section 3.1 we explained how credit and asset prices can both precede very low and very high inflation). Strikingly, the credit, house price and government bond yield signals for low inflation have a longer lead time than for high inflation: the lead of the significant credit and house price signals for low inflation ranges from 0 to 8 quarters, whereas the significant leads of credit and house price signals for high inflation are mostly limited to a range of 0 to 3 quarters. Compared to the signals of credit and house prices, the lead times of the significant equity signals for high and low inflation are even longer in most cases, probably because market prices quickly process information on future developments in the economy and inflation.

[insert Figure 9]

The lead time between the peak signal of low sovereign bond yields with respect to low inflation/deflation is quite short in most countries (Figure 9, panel b). Bond yields can affect inflation through their effect on credit and asset prices, as explained in Section 3. Figure 10 confirms that high (low) equity and house prices were preceded by two-year episodes of low (high) long-term bond yields.

[insert Figure 10]

4.2 Logit model estimation results

We estimate logit models, for both low inflation/deflation and high inflation, for four selected countries, i.e. the US, Germany, Japan and the Netherlands, for which data availability was sufficient for the estimation. We include the financial variables credit, equity, housing prices and the government bond yield into all models. The length of the corporate bond rate time series is too short for inclusion. We also add real GDP in deviation from its trend, to control for any real business cycle effects. Including GDP also controls for fundamental drivers of asset prices, which helps to distinguish bubbles from more sustainable developments in asset prices and credit growth. We include 8 to 5 lags for all four variables. Including lags 4 to 0 did not improve the fit or lead to singularity because of lack of observations.[7]

[7] Panel logit models, including fixed effects for all countries, have also been estimated including 1 to 3 independent financial variable at a time with 0 to 8 lags. The estimates were insignificant and/or had a poor fit.

Table 2 presents the estimation results. Several statistics denote the models' abilities to predict the inflationary regime. First, the Pseudo-R^2 gives the overall model fit. Second, the percentage of correct classifications gives the percentage of observations for which the model correctly predicts the inflationary stance. Note that for this classification, the threshold for the predicted probabilities is always set to the default value of 0.5. I.e., if the predicted probability at a particular point in time exceeds 0.5, the inflation dummy at that moment is predicted to be equal to 1 (meaning, for example, high inflation), and otherwise 0 (normal inflation). Third, the area under the ROC curve (AUROC), discussed in Section 2, is a statistic encompassing all possible thresholds used for such classifications.

[insert Table 2]

Overall, the logit models have a high fit, indicating that financial variables are important in explaining high and low inflation regimes. According to the R^2, correct classifications and AUROC statistics, the models explaining the low inflation/deflation regime perform better in the US and Japan than the models explaining the high inflation regime, while the opposite is true for Germany and the Netherlands. Overall, the sovereign bond yield has most explanatory power for both high and low inflation regimes, as this variable has most significant lags in the models. The contribution of house and equity prices is ambiguous; in some cases these variables are significant in the high inflation models and in some cases in the low inflation/deflation models.

Figure 11 plots the (in-sample) predicted probabilities of high and low inflation/deflation, respectively, for the four selected countries. These probabilities, being in a range of 0 to 1, are plotted against the values of the inflationary regime dummy variable, being either 0 or 1. The figure shows that in particular the low inflation regimes, which are concentrated at the end of the sample period, are predicted relatively accurately by the logit model.

[insert Figure 11]

4.3 Policy implications

Our results indicate that stimulating asset prices – one of the main transmission channels of QE - can be effective in influencing inflation. This suggests that the asset price channel (or portfolio rebalancing channel) can be effective. However this goes with several uncertainties and risks. The dynamics of asset prices are different for each asset category, while booms and busts are usually driven by interactions between credit, interest rates and asset prices. Our results show that high asset prices can precede an episode of either very high or low inflation. For QE, this finding implies that its stimulating effects on asset prices may lead to booming asset markets feeding into very high inflation and in the longer term to very low inflation if an asset price bubble bursts. Low government bond yields also signal low inflation. While central banks intend to raise inflation by purchasing government bonds to reduce bond yields, our results indicate that this policy can have the opposite effect on inflation. The literature identifies several channels through which (a prolonged period of) low interest rates can undermine economic growth and hence inflation (see for instance Arrowsmith et al., 2013 and Gopinath et al., 2015).

The results imply that QE can have perverse effects, which may work against the objectives of the central bank. Not only financial stability but also the inflation target can be compromised by excessive asset price developments. Hence, central banks should closely monitor the signals that asset prices and interest rates give for future price stability. These signals could inform the central bank whether QE is stretching asset markets too much relative to the inflation objective. Asset prices should be a key indicator in the information set of central banks. A complicating factor is that there can be long lags in the transmission of asset prices to inflation. The long lead time of equity prices suggests that the transmission process of financial market developments to inflation can be long-lasting. This implies that central banks should be patient in seeing the effects of QE coming true. The overall conclusion from the results is that it is notoriously hard to assess if and when asset price developments present a risk to price stability.

5. Conclusion

We investigate the information content of financial variables such as stock prices, private credit and interest rates, as signalling devices of two possible inflationary regimes: (1) very low inflation or deflation, and (2) very high inflation. We use the receiver operating characteristic (ROC) curve to determine the signalling content of each financial variable separately, varying the number of quarters lead time from 0 to 8. Next, we estimate logit models including several financial variables in one equation and calculate predicted probabilities for inflationary regimes.

Our results indicate that high asset prices are more often signalling high inflation than low inflation/deflation. However, in some countries in our sample, high asset prices are a significant indicator of low inflation as well. The lead times indicate that the transmission of high credit and asset prices to episodes of very low inflation/deflation can be quite long, ranging up to eight quarters. Low government bond yields, as a rule, do not give a significant signal for high inflation, while they do for low inflation/deflation. The high fit of the logit models confirm that financial variables are important in explaining high and low inflation regimes.

These results indicate that stimulating asset prices – one of the main transmission channels of QE - can be effective in influencing inflation. However the effects are quite uncertain, both in timing and direction.

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APPENDIX A. Data description

Variable names, definitions and sources. Quarterly time series 1985Q1 till 2014Q4 (if available) for US, Japan, UK, Germany, France, Italy, Netherlands, Australia, Norway, Sweden and Spain		
Variable	***Definition***	***Source***
Private credit	Domestic bank loans outstanding to households and firms and debt securities issued by the non-financial corporate sector. Detrended by Hodrick-Prescott filter.	BIS
House price	Residential property price index. Detrended by Hodrick-Prescott filter.	OECD
Stock prices	Representative stock market index for each country. Detrended by Hodrick-Prescott filter.	BIS
Government bond yield	10 years government bond yield. Detrended by Hodrick-Prescott filter.	Thomson Reuters
Corporate bond rate	Rate on an aggregate corporate bond index. Detrended by Hodrick-Prescott filter.	Thomson Reuters
Inflation	Year-on-Year percent change of Consumer Price Index	IMF

TABLES

Table 1. Inflation statistics and regimes

Sample period 1985 – 2014, quarterly data

	Mean inflation (%)	Standard deviation of inflation (%)	Very high inflation (number of obs.)	Very low inflation/ deflation (number of obs.)	Normal inflation (number of obs.)
Germany	1.76	1.19	13	13	90
Norway	2.79	1.99	14	7	95
Sweden	2.52	2.74	15	9	92
Australia	3.53	2.39	23	8	84
United Kingdom	3.51	1.98	12	12	92
United States	2.77	1.27	16	14	86
Japan	0.51	1.29	21	14	80
France	1.90	0.91	23	17	76
Italy	3.26	1.78	26	15	75
Spain	3.66	2.05	18	14	84
Netherlands	1.95	1.05	14	17	85

Table 2. Logit estimation results for United States, Germany, Japan, Netherlands.
Dependent variable is high dummy and low inflation/deflation inflation dummy, respectively

	United States		Germany		Japan		Netherlands	
Explanatory variables	High inflation	Low inflation/ deflation	High inflation	Low inflation/ deflation	High inflation	Low inflation/ deflation	High inflation	Low inflation/ deflation
Credit $_{t-5}$	-6.271 (7.434)	10.864 (7.191)	7.693 (5.052)	13.635* (8.362)	2.782 (3.514)	1.547 (2.965)	1.894 (3.617)	-2.943 (2.923)
Credit $_{t-6}$	2.385 (7.319)	18.517*** (6.653)	-3.525 (4.940)	-5.581 (7.409)	-4.632 (4.193)	-3.238 (3.327)	1.838 (3.539)	3.444 (3.580)
Credit $_{t-7}$	-4.081 (6.979)	8.783 (11.268)	-21.947** (10.990)	-7.973 (6.608)	2.565 (3.756)	-2.337 (3.510)	-2.667 (3.301)	0.473 (3.498)
Credit $_{t-8}$	7.238 (6.625)	-10.090 (7.642)	7.533 (5.938)	-0.151 (5.920)	-11.004** (4.370)	1.898 (3.602)	1.400 (3.493)	1.755 (2.890)
Equity $_{t-5}$	-0.379 (0.470)	0.198 (0.572)	-0.037 (0.332)	0.119 (0.276)	0.362 (0.539)	0.095 (0.451)	-0.292 (0.410)	-0.237 (0.389)
Equity $_{t-6}$	0.396 (0.569)	-0.079 (0.461)	0.672 (0.546)	0.134 (0.415)	0.177 (0.842)	0.506 (0.660)	-0.403 (0.535)	0.649 (0.488)
Equity $_{t-7}$	-0.889 (0.155)	0.595 (0.710)	-0.967* (0.543)	0.040 (0.563)	0.060 (0.814)	-0.668 (0.705)	0.721 (0.534)	0.394 (0.551)
Equity $_{t-8}$	0.191 (0.5454)	1.126** (0.585)	0.882** (0.421)	-0.682 (0.506)	0.669 (0.579)	1.709*** (0.637)	0.139 (0.494)	-0.121 (0.477)
Housing price $_{t-5}$	5.659 (8.981)	-11.868 (7.512)	3.711 (7.362)	-0.547 (7.797)	15.117 (14.473)	-12.617 (33.723)	-4.108 (2.947)	1.291 (3.295)
Housing price $_{t-6}$	-7.682 (17.112)	18.304** (9.665)	-1.070 (9.309)	-16.340 (15.784)	-24.061 (20.274)	16.234 (46.882)	-3.142 (3.400)	-1.246 (3.626)
Housing price $_{t-7}$	-4.994 (17.170)	8.900 (12.061)	3.890 (10.741)	17.995 (15.565)	16.290 (22.596)	-2.263 (32.565)	11.223** (5.288)	-0.098 (4.948)
Housing price $_{t-8}$	11.232 (11.558)	-34.326** (13.787)	-11.678 (8.975)	-5.880 (8.704)	4.771 (15.195)	7.666 (20.433)	-8.167*** (2.668)	-1.385 (4.611)
Government bond yield $_{t-5}$	-0.051 (0.118)	0.176* (0.106)	0.018 (0.095)	0.196 (0.160)	0.110 (0.157)	-0.025 (0.141)	0.071 (0.130)	-0.006 (0.131)
Government bond yield $_{t-6}$	-0.168 (0.172)	0.197 (0.168)	0.162 (0.141)	-0.043 (0.152)	-0.107 (0.182)	-0.282 (0.179)	0.099 (0.214)	-0.036 (0.202)
Government bond yield $_{t-7}$	0.153 (0.192)	0.205 (0.195)	-0.099 (0.158)	-0.192 (0.170)	-0.026 (0.160)	0.295 (0.254)	0.075 (0.166)	-0.229 (0.225)
Government bond yield $_{t-8}$	0.055 (0.137)	-0.085 (0.116)	0.216* (0.128)	0.357** (0.172)	-0.322** (0.151)	-0.463*** (0.173)	-0.250** (0.129)	0.287* (0.174)

Table 2 (Continued).

Real GDP $_{t-5}$	18.759** (7.877)	1.473 (8.152)	-5.676 (5.087)	-3.079 (4.841)	3.867 (4.183)	-0.719 (3.154)	7.484 (8.346)	-6.660 (6.287)
Real GDP $_{t-6}$	1.000 (10.464)	-7.513 (9.303)	4.619 (5.752)	13.596 (8.667)	3.628 (5.077)	1.898 (4.127)	-0.612 (8.587)	1.885 (7.125)
Real GDP $_{t-7}$	-0.513 (10.756)	0.495 (10.746)	1.403 (4.040)	-11.959 (7.936)	1.695 (5.196)	-6.107 (5.207)	2.371 (10.103)	7.561 (6.726)
Real GDP $_{t-8}$	-3.263 (9.569)	5.880 (7.260)	-6.206 (4.035)	8.208* (8.208)	-5.914 (4.643)	0.347 (4.713)	6.462 (8.744)	-4.454 (6.434)
Pseudo R^2	0.311	0.646	0.649	0.488	0.421	0.602	0.571	0.207
% correctly classified	88.89	95.83	95.10	93.94	85.57	94.44	93.88	87.76
AUROC	0.850	0.967	0.966	0.929	0.897	0.957	0.957	0.819
Number of observations	99	96	102	99	97	90	98	98
Explanatory note. Marginal effects are presented, with robust standard errors within parentheses. ***/**/* denote significance at the 1%/5%/10% level.								

FIGURES

Figure 1. Stock price indices and Quantitative Easing (QE)

Figure 2. Signal and outcome

	Abnormal inflation	Normal inflation
Signal	A	B
No signal	C	D

Figure 3. ROC and AUROC

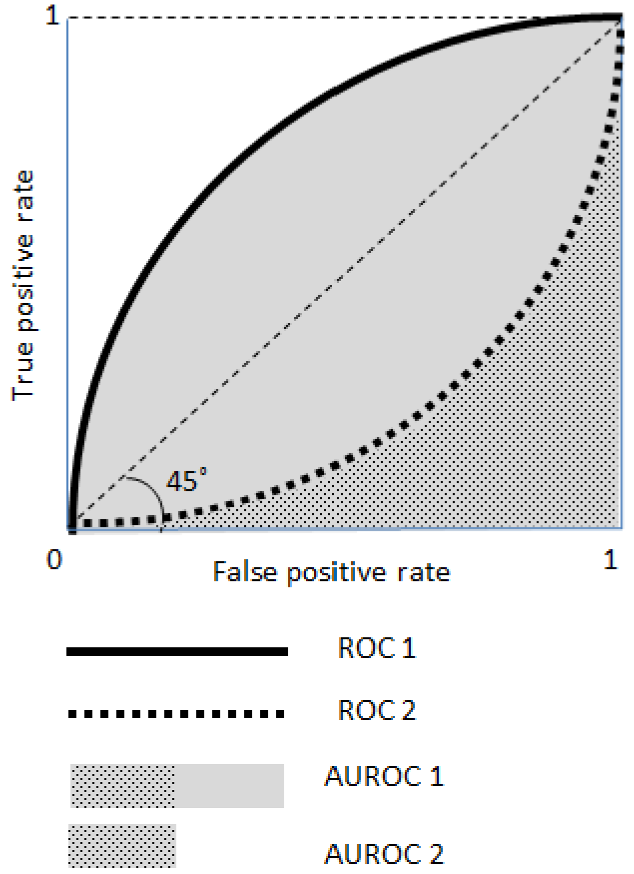
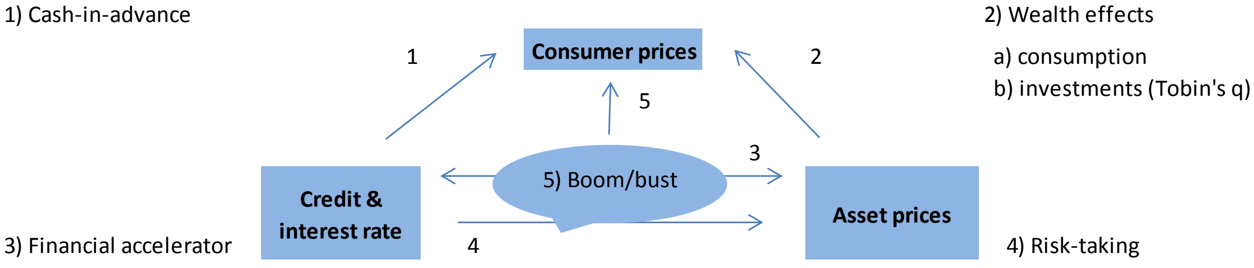
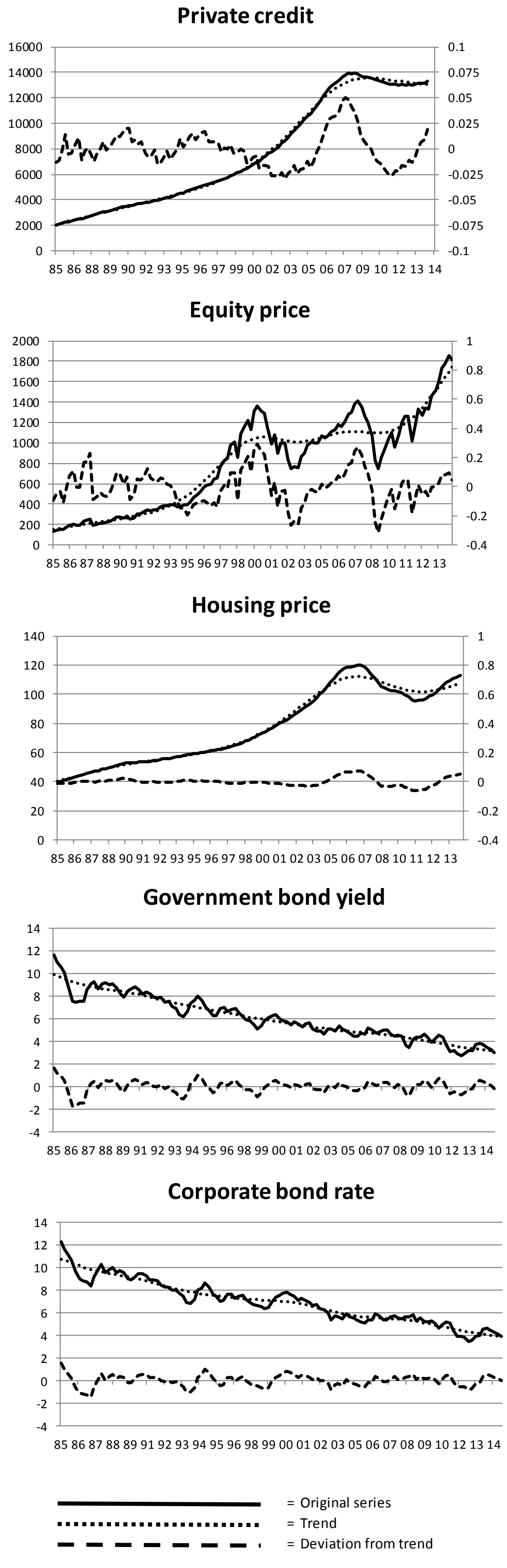


Figure 4. Transmission channels



Note: Figure is based on Papademos and Stark (2010).

Figure 5. Financial variables, United States



Note. Deviations from trend: for credit and asset prices these are ratios with respect to their trends (right hand scale); for interest rates differences from their trends. Trends have been calculated using the Hodrick-Prescott filter.

Figure 6. Inflationary episodes, United States

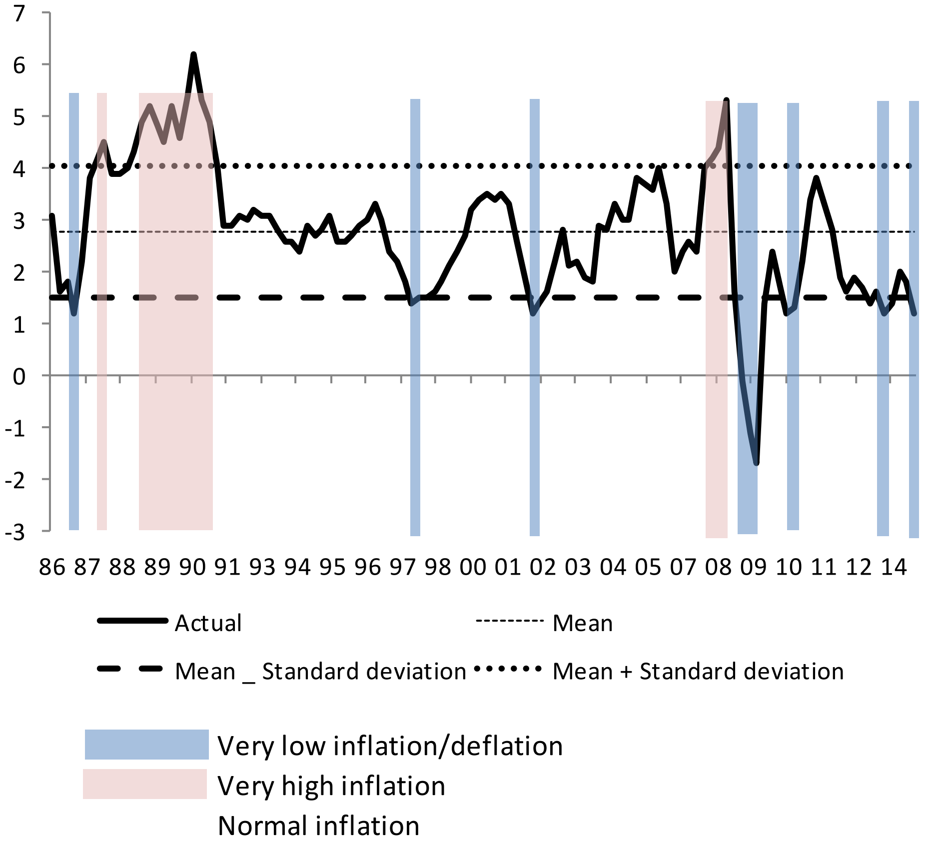
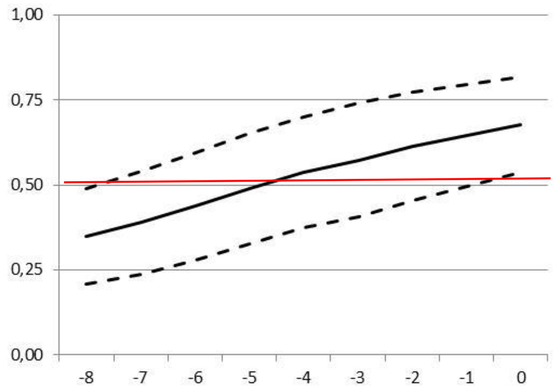
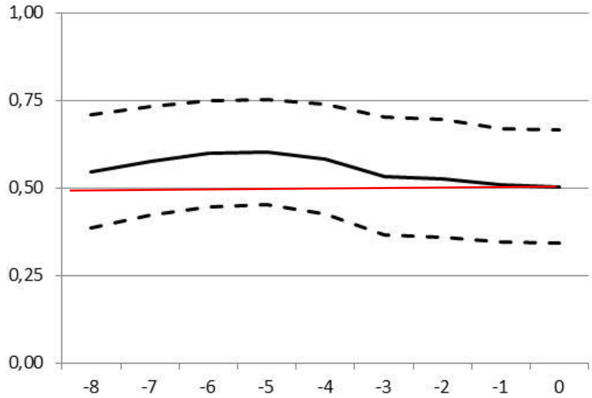


Figure 7. AUROC for different leads; averages over 11 countries

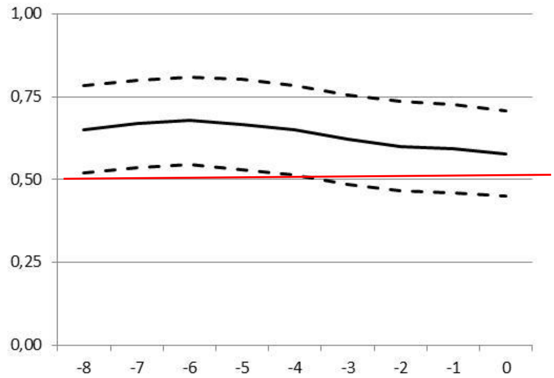
a. Higher credit signalling high inflation



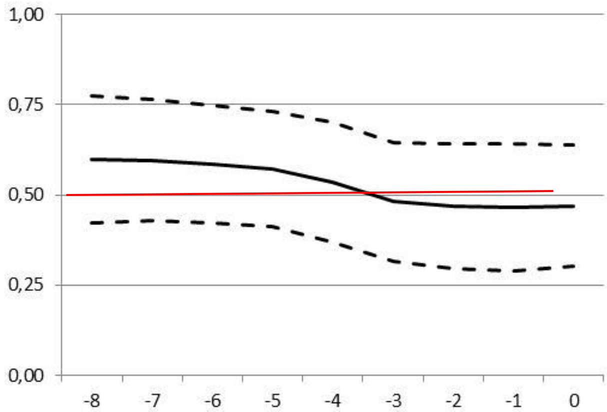
b. Higher credit signalling low inflation



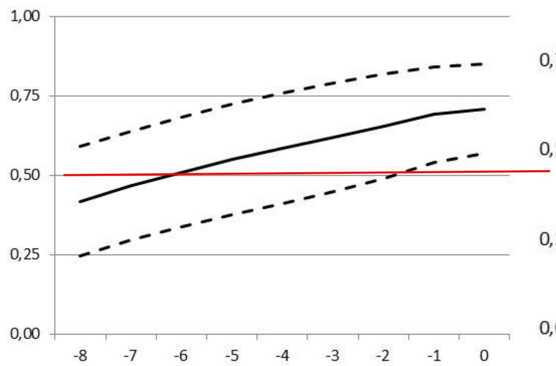
c. Higher equity price signalling high inflation



d. Higher equity price signalling low inflation



e. Higher house price signalling high inflation



f. Higher house price signalling low inflation

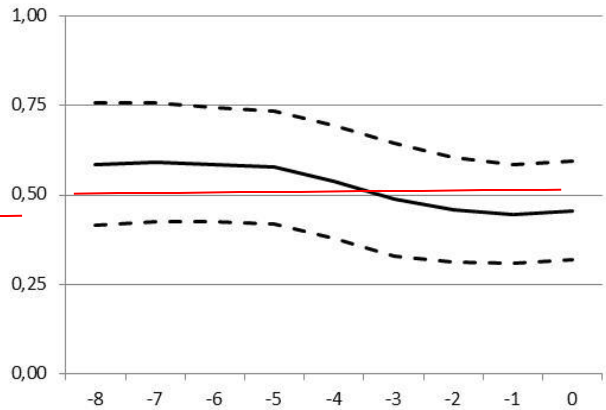
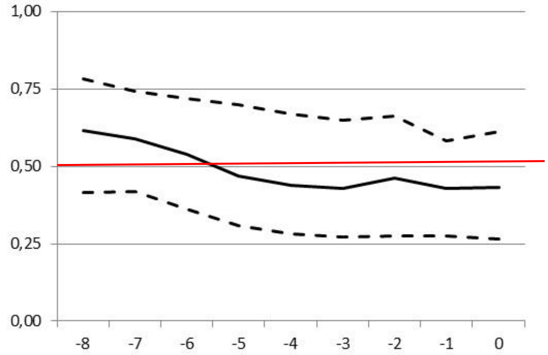
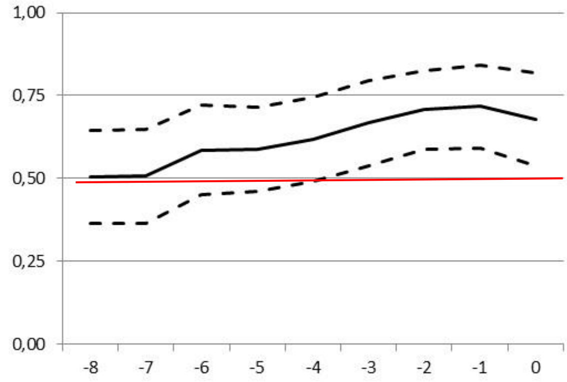


Figure 7-continued. [1 – AUROC] for different leads; averages over 11 countries

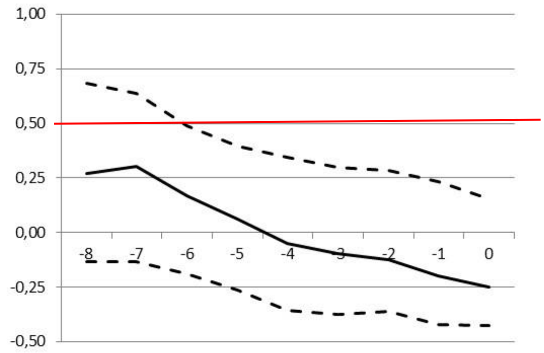
g. Lower government bond yield signalling high inflation



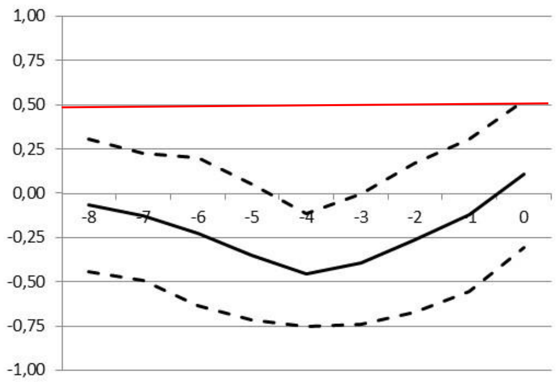
h. Lower government bond yield signalling low inflation



i. Lower corporate bond rate signalling high inflation



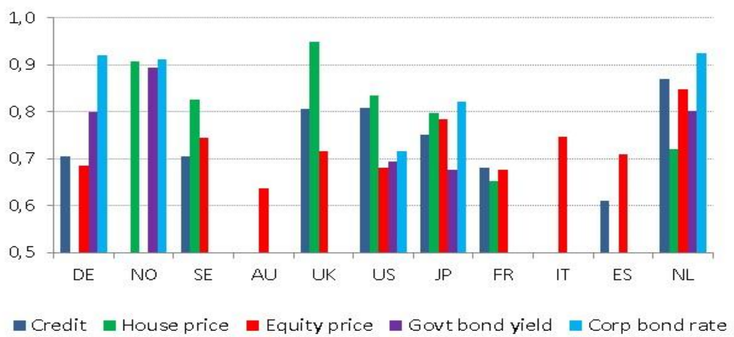
j. Lower corporate bond rate signalling low inflation



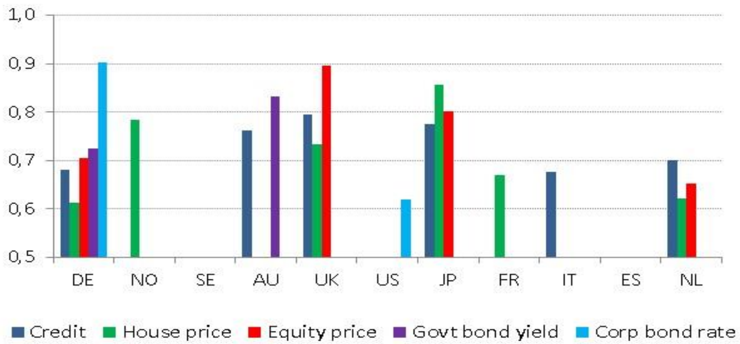
Note: Dotted lines denote 95% confidence bands. Signal is informative if the lower confidence bound > 0.5 (red line).

Figure 8. Maximum signalling value (areas under the ROC curve) for lead time 8 to 0 quarters, by country

a. Maximum signal for high inflation



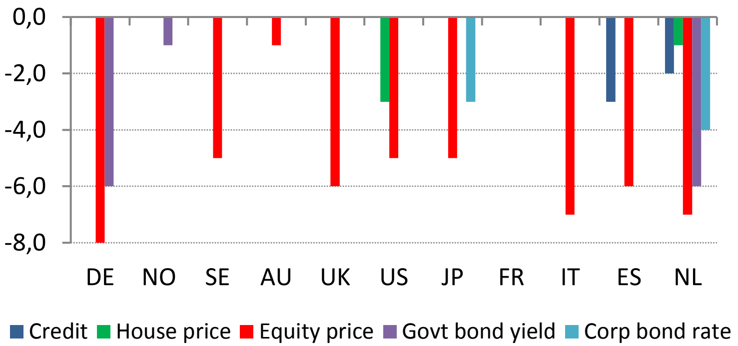
b. Maximum signal for low inflation/deflation



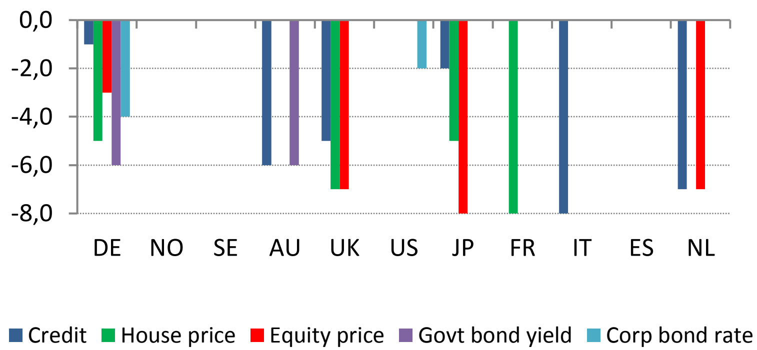
Note: Lead times have been chosen that gives maximum signals (on vertical axis). Significant signalling values extracted from high (above trend) levels of credit, house and equity prices (i.e., lower confidence bound AUROC > 0.5). Significant signalling values extracted from low (vis-à-vis mean) levels of sovereign and corporate bond yields (i.e., lower confidence bound [1 – AUROC] > 0.5). Insignificant AUROC values on vertical axis below 0.5 are not shown.

Figure 9. Lead of maximum signal

a. Lead of maximum signal for high inflation



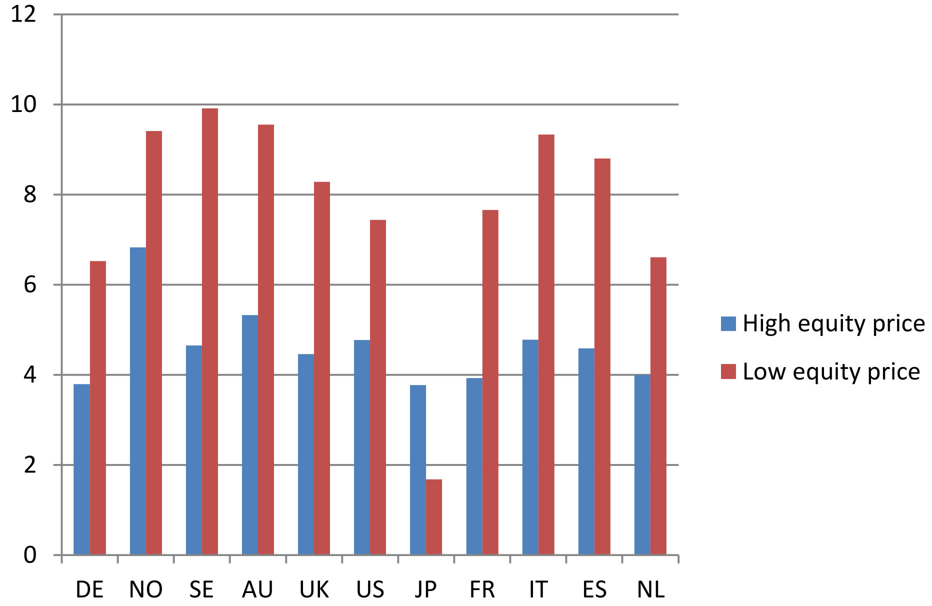
b. Lead of maximum signal for low inflation



Note: Lead times (on vertical axis) have been chosen that gives maximum signals (in several cases the lead time is zero, implying that no bar is shown). Significant signalling values extracted from high (above trend) levels of credit, house and equity prices (i.e., lower confidence bound AUROC > 0.5). Significant signalling values extracted from low levels of sovereign and corporate bond yields (i.e., lower confidence bound [1 – AUROC] > 0.5).

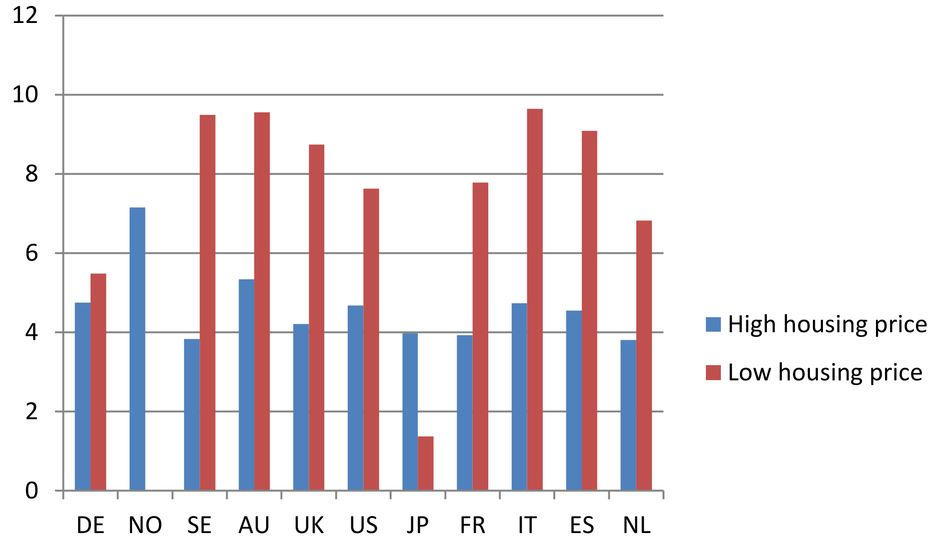
Figure 10. Government bond yields and asset prices

a. Average government bond yield two years preceding high (or low) equity prices



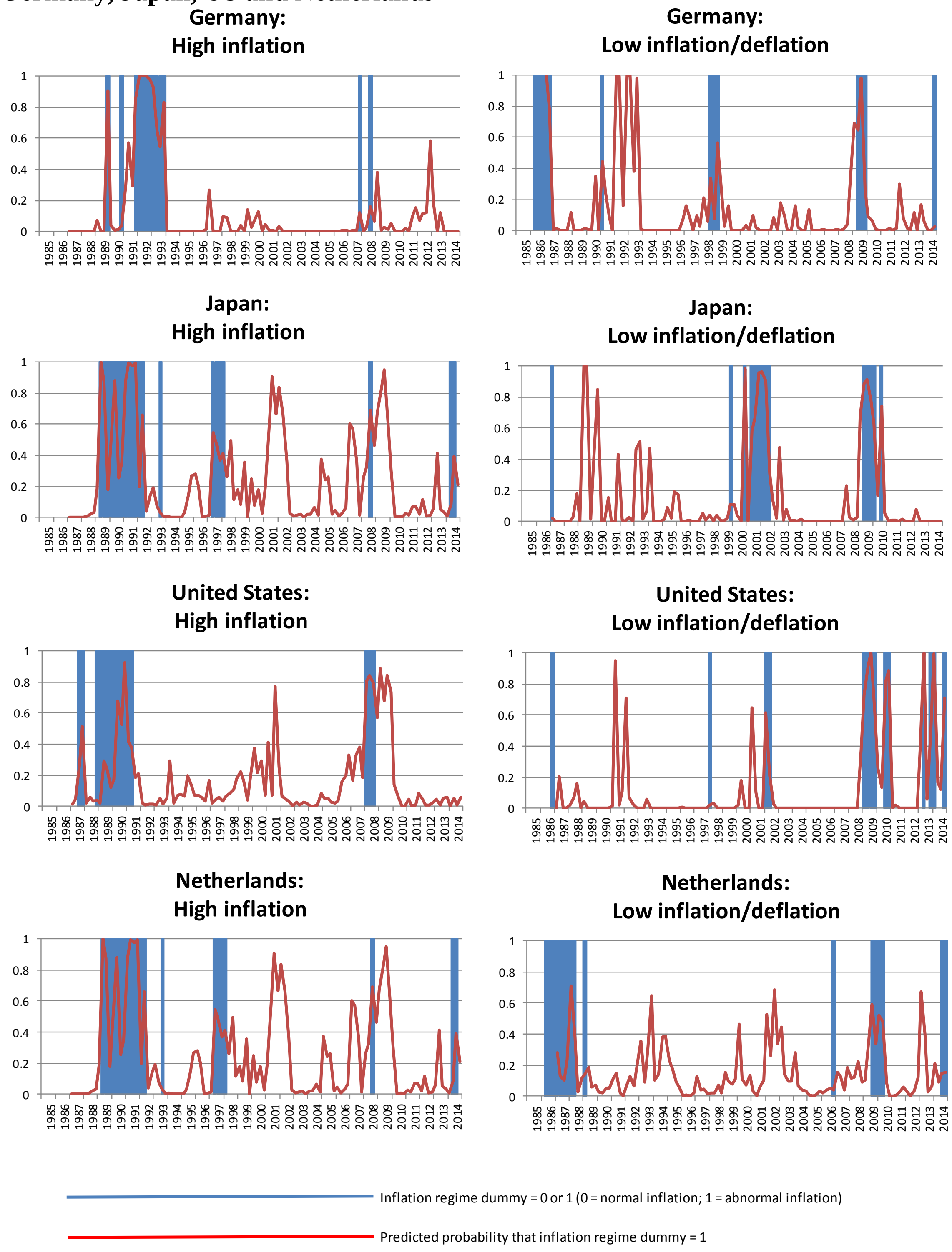
High (low) equity price = above (below) the median of sample period.

b. Average government bond yield two years preceding high (or low) housing prices



High (low) housing price = above (below) the median of sample period.
Norway: Missing observations for interest rate in low housing price period.

Figure 11. Predicted probabilities of high and low inflation/deflation, respectively, for Germany, Japan, US and Netherlands



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